Courthouse Square

Office Floor Slab – Structural Evaluation DRAFT COPY

Prepared For:
Marion County
100 High St. NE
Salem, OR 97309

Prepared By:
David Evans and Associates, Inc.
2100 SW River Parkway
Portland, OR 97201

January 2008

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DEA Project No. MARN0000-0036

January 2008

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Appendices

11x17

8½x11

INTRODUCTION

David Evans and Associates, Inc. (DEA) has been retained by Marion County to conduct a structural evaluation of the office floor slab (Appendix A) at the Courthouse Square office building in Salem, Oregon to assist in determining the possible cause or causes of excessive slab deflection.

The Courthouse Square office building is a five story, approximately 160,000 square foot, reinforced concrete building which is co-occupied by Marion County and Salem Keizer Transit. In addition to the building, the site also has one level of underground parking and a bus mall (adjacent to the building).

The 1997 Uniform Building Code (UBC) as amended by the State of Oregon was used as a basis for our assessment of the floor slab. Our evaluation includes limited site visits to observe the general physical status of this structure. We have also reviewed multiple construction documents, including the existing drawings dated December 30, 1998, prepared by Arbuckle Costic Architects of Salem, Oregon. Our findings have been compiled in this report.

EXECUTIVE SUMMARY

As part of this evaluation, DEA has reviewed the existing conditions, the existing drawings and multiple construction documents. We have also performed independent structural calculations to verify the behavior of the floor slabs and conducted two types of non-destructive testing to confirm as-built conditions. Based on all of these things, and our experience with structures of similar construction, likely causes of the excessive slab deflection at the Courthouse Square building have been narrowed to the following:

- Incorrect Placement of Steel Reinforcement
- Concrete Shrinkage
- Concrete Creep
- Premature Removal of Formwork
- Improper Concrete Curing

The non-destructive testing showed that the post-tensioned tendons were incorrectly placed within the floor slab. The testing also suggested that it is possible the incorrect number of tendons were placed within the floor slab. Structural calculations completed by DEA show that this error would be expected to account for up to an additional 1” of deflection. While this does not account for all of the additional deflection the floor slab is experiencing, it accounts for a great deal of it. It is DEA’s opinion that in addition to this error, one/some of the above mentioned causes are causing the remainder of the excess deflection.

It should be noted that DEA cannot declare that the floor slab is structurally adequate to support the vertical dead and live loads (this was not part of DEA's original scope of work). DEA recommends that Marion County obtain a structural engineer to perform an allowable load capacity analysis on the floor slab to determine if it is adequate for service loads.

EXISTING CONDITION

The existing building (constructed in 2000) is located on the south side of the block bounded by NE Chemeketa St., NE Church St., NE Court St. and NE High St. in Salem, Oregon. The building is a five story reinforced concrete structure and has one level of below ground parking. The architect was Arbuckle Costic Architects, Inc. The structural engineer was Century West Engineering, Corp. The contractor was Pence Kelly Construction, Inc. The special inspector was Carlson Testing.

The foundation consists of concrete slab on grade with independent column footings and a perimeter reinforced concrete retaining wall. Lateral resistance for the building is provided by reinforced concrete shearwall core elements surrounding the two stairwells. These shearwalls are supported by a reinforced concrete mat foundation.

The typical elevated floor construction consists of a 10" thick unbonded post-tensioned reinforced concrete floor slab. Post-tensioning is desirable for multi-story buildings because it can produce thinner concrete sections, longer spans between supports and produces fewer, visible cracks. Unbonded post-tensioned elements are generally cast in their final location (cast-in-place). The concrete is post-tensioned by tendons that consist of steel strands fabricated from multiple individual wires enclosed in a sheath or duct. The annular space between the strand and the sheath or duct contains grease, which serves to lubricate the tendon and inhibit corrosion. The untensioned tendons are placed in the formwork and secured at the correct location, spacing and profile (distance from bottom of floor slab to centroid of steel tendon). The concrete is cast and allowed to harden. After the concrete reaches a predetermined strength, the strands are tensioned and the stress is locked into each tendon at the anchor assembly. The presence of the sheath around the strand does not allow the concrete to contact (or bond to) the strands, creating an unbonded system. Unbonded post-tensioned systems are generally constructed using monostrand tendon assemblies. These strands are generally fabricated with multiple individual 270 ksi wires. The sheath is extruded around the strand, creating a sheath that is relatively impermeable. The grease is injected into the annular space as the sheath is extruded around the strand. The anchorage for an unbonded monostrand system consists of a cast plate in which the tendon is gripped by a two-piece set of wedges. The strand is stressed, and the conical-shaped wedges are inserted into the bearing plate to provide anchorage. Typical unbonded post-tensioned reinforced concrete construction consists of singular (distributed) tendons spaced equal distance apart spanning to grouped (banded) tendons which act as beams spanning to bearing elements (columns or walls). In addition to post-tensioning elements, mild reinforcement is also typically included at both the top and bottom layers of the slab. Mild reinforcement not

only adds flexural and shear strength to a slab, it also helps mitigate shrinkage cracks and acts as collectors for lateral loads.

Special inspection is required on all post-tensioned structural elements. Some of the duties that may be required of the special inspector include verifying that the reinforcing steel and tendons are accurately placed and adequately supported and secured against displacement during placement of concrete, verifying that the steel stressing ram is properly calibrated, verifying that the tendons are stressed only after the concrete has achieved the proper strength and in the proper sequence and verifying that the final stressing steel tension forces and final elongations are in compliance with the project specifications. Special inspection is crucial in ensuring the structure behaves as designed.

The typical Courthouse Square slab was detailed (Appendix B/Appendix C) to include banded post-tensioned tendons running in the north-south direction and distributed post-tensioned tendons running in the east-west direction. The permit drawings do not specify the number/spacing of the banded/distributed tendons, but indicate the forces to which these elements must be designed. Based on these forces, the post-tensioning supplier must coordinate the number of tendons required at each location. In addition to the post-tensioned reinforcement, a uniform mat of bottom mild reinforcement was shown to be included in both directions. Mild reinforcement was only shown to be included at the top layer of the slab over the columns. Dywidag bars were also shown at the shearwall locations as collector elements for the buildings lateral loads.

The typical building floor slab was divided into equal east and west sections separated by a pour strip at the center of the building. Pour strips are strips of slab that are poured after the adjacent slabs are placed to allow for unrestrained shrinkage to occur. Pour strips are typically filled after a prescribed amount of time has passed and all stressing operations have been complete.

SCOPE

As part of the original structural evaluation agreement, DEA provided a list of tasks to be completed leading up to this final report. A summary of DEA's contracted tasks and results is listed below.

Task 1.0 Floor Elevation Survey

DEA performed two surveys of the fifth floor slab (at the location bounded by grids K-M and 10-11). The first survey (performed on June 6, 2007) consisted of using a manometer to spot measure 15 pre-selected locations. The initial survey results (Appendix I), when compared with the recommended maximum allowable deflection criteria (Section 16, '97 UBC), confirmed that the floor slab was experiencing excessive deflection.

The second survey (performed on December 20, 2007) duplicated the initial survey in location and methodology with the intent of verifying whether or not the slab had

undergone additional deflection since the first survey. The second survey results (Appendix J) showed that the slab had not experienced additional deflection since the initial survey was completed.

Task 2.0 Construction Document Review

DEA spent approximately five days sorting thru/reviewing construction documents provided by Arbuckle Costic Architects, Marion County and Pence Kelly. Items reviewed include the following: permit drawings, as-built drawings, project specifications, structural calculations, requests for information (RFIs), shop drawings, special inspection reports, concrete mix designs, meeting notes, memos, photographs, contractors' project schedule, emails, structural observations and field sketches. Several of these documents have been attached as appendices and are discussed at further length later in this report.

Task 3.0 Slab Design Review

DEA analyzed five different fifth floor slab segments (Appendix M)to replicate the deflection behavior of the slabs based on the shop drawings found during Task 2.0. The intent of this task was to compare the design deflections versus the as-built deflections measured in the surveys discussed above. These calculations/measurements would then be compared with the recommended maximum allowable deflection criteria specified in the UBC (length or span of slab/240).

The slabs were analyzed using ADAPT-PT, a software program used for the design of one-way and two-way post-tensioned floor systems and beams. Design parameters (number of tendons, profile of tendons, etc.) were based on the reviewed shop drawings found in Task 2.0. Preliminary calculations showed that the modeled slabs deflected less than the recommended maximum allowable deflection criteria and the as-built deflection measurements:

Survey Information				
	in.	in.	in.	in.
Location	Surveyed Deflection (DL+LL)	l/240	Calculated Deflection (DL+LL)	$\Delta_{\text{surveyed vs calculated}}$
K/10.5	1.86	1.9	1.02	0.84
L/10.5	3.42	1.9	1.75	1.67
M/10.5	3.12	1.9	1.77	1.35

This suggests that the original design met the maximum allowable deflection criteria specified in the UBC. However, per the permit drawings, the only top mat reinforcement called out in the fifth floor slab is #4 at 24" on center at the pour strip and (8) #6 each way at the columns. Based on the slab analysis outlined above, this appears to be a less than adequate amount of top mat reinforcement.

DEA updated the design parameters (based on the information revealed during the non-destructive testing outlined in Task 4.0) and repeated the calculations to obtain more

accurate results. Due to the fact that the non-destructive testing was only completed at Grid L, only those calculations could be revised. These calculations showed that based on the non-destructive testing results, the modeled floor slab deflected more than the maximum allowable deflection criteria specified in the UBC.

Survey Information				
	in.	in.	in.	in.
Location	Surveyed Deflection (DL+LL)	l/240	Calculated Deflection (DL+LL)	$\Delta_{\text{surveyed vs calculated}}$
L/10.5	3.42	1.9	2.79	0.63

The difference in the two sets of deflection calculations is related to the profile of the tendons. The testing (per Task 4.0) revealed that the banded tendons along Grid L were not placed per the design/shop drawings. This implies that the original design was adequate and that there was an error placing the post-tensioning during construction.

Task 4.0 Tendon Anchor Inspection

In order to verify what the existing slab construction consisted of, DEA commissioned two types of non-destructive testing to be completed at the surveyed area of the fifth floor slab: ground penetrating radar (GPR) and radiography (X-ray).

GPR is used to locate tendons and reinforcing bars in slabs, joists and beams. The electromagnetic pulse reflects off interfacial surfaces and the reflected wave is received and analyzed. It can also be used to pick up voids and poorly consolidated regions of the concrete member.

X-rays are used to precisely locate tendons in a structural member. They are also used to differentiate between steel tendons and reinforcing bars. In addition, X-rays can detect breaks or fractures in individual wires.

GPR was performed on December 7th, 2007 to identify and profile the depth (profile) of banded post-tension cables running north to south at Grid L. Testing results (Appendix G) showed that the as-built profile measurements did not match the design documents. The post-tensioning shop drawings (Appendix C) show a profile 1" at mid-span of the floor slab. The as-built measurements show a profile of 1¾" at mid-span of the floor slab. This means that the tendons were placed higher in the slab than what was shown on the shop drawings. In addition to the profile being different at the mid-span of the floor slab, the GPR testing results revealed the profile as being consistently shallow throughout the floor slab (along Grid L).

In general, the lower the post-tensioning is placed in a concrete element, the more flexural strength and stiffness that element attains. Due to this fact, the placement of the post-tensioning is extremely critical to the performance of a post-tensioned structural element. Per the deflection calculations noted above, this minor change in the profile accounts for approximately 1" of additional deflection. Although this change in the

placement of the post-tensioning does not account for the total difference between design deflection (based on the shop drawings) and the as-built measured deflection, it is possible other factors (discussed at further length later in this report) also contributed to the excess deflection of the floor slab.

GPR testing results also identified the distributed tendons in the slab spaced approximately 24" on center. Mild reinforcement spacing was concluded to be 12" on center in the north-south direction and 24" on center in the east-west direction. These results match the shop drawings (Appendix F).

X-rays were performed on December 8th, 2007 to identify the number of banded cables running north to south at Grid L. Based on the x-ray results (Appendix H), it appears there are a total of 52 steel tendons running north to south at Grid L, which is slightly less than the 54 steel tendons that are shown on the shop drawings (Appendix C) and the elongation reports (Appendix E). While it is possible that a fewer number of tendons were placed in the slab during construction than were called for on the drawings, it is also possible that the extents of the x-rays was not large enough to capture all 54 tendons. Due to this uncertainty, the revised calculations noted above were performed using the as-built profile measurement from the GPR testing and a total of 54 tendons.

Removal of brick veneer to expose the slab edge for inspection of the steel tendon anchors was not completed in this task due to the fact that there was no indication that the steel tendon anchors had displaced. As this task would have been highly destructive and labor intensive, it was decided it was not worth the effort to complete.

OBSERVATIONS

Our observations were drawn from multiple walk-throughs of the structure, review of existing drawings, non-destructive testing, calculations and our experience with structures of similar construction.
Several areas of damage were noted on the fifth floor during DEA's site visits (Appendix K). Gaps at tops of partition walls, horizontal/vertical cracking at tops of door frames, sticking doors, separation of door frames from partition walls and damaged ceiling framing are some of the areas of damage that were noted over the course of this evaluation. (It should be noted that the observed damage was not limited to the slab location noted below.)

Based on the survey data, the fifth floor slab is experiencing excessive deflection at the area bounded by grids K-M and grids 10-11. No tension cracks were observed at the underside of the floor slab. It appears that the damage noted above (at least at this precise location) is occurring due to the excessive deflection the slab is experiencing.

Another area of damage noted during DEA's site visits was the expansion joint at the bus mall. There is an isolation joint in the ground floor slab between the Courthouse Square building and the bus mall. The gap at this joint has increased enough to cause the joint filler to separate from the brick paving units and one of the metal plate joint covers over

the brick to lose support at one side. This increased gap appears to be the result of concrete shrinkage and is a cosmetic problem, since the structure is supported on either side of the joint by an independent row of columns.

DEA reviewed several construction documents as part of the evaluation process. The following is a list of the key items reviewed with a summary on what was found for each:

- Permit Drawings –
  A set of permit drawings (issued December 30, 1998) was found and reviewed for completeness and conformance with the as-built structure. No errors/omissions were noted on the permit drawings.
- As-built Drawings –
  A set of as-built drawings (permit drawings with notes and revisions made during construction) was found and reviewed for significant design changes that would affect the behavior of the post-tensioned floor slab. No significant changes were noted on the as-built drawings.
- Project Specifications –
  Project specifications (Appendix F) were reviewed for information regarding the construction and testing of the post-tensioned floor slab. Specific sections that were reviewed included Concrete Formwork, Reinforcing Steel, Stressing Tendons and Cast-in-Place Concrete. The following items were noteworthy:
    - Section 03230 : Stressing Tendons –
      Specification required that the owner engage a testing laboratory to perform field tests, including the following:
        - Inspect placement and post-tensioning of strands.
        - Verify size, number, location and drape of strands and post-tensioning loads imposed.
        - Keep a daily record of jack gage pressures, measured tendon elongations and computed forces based on each of the parameters for each tendon.
        - Record jacking procedures and stressing order for each slab.

      This requirement appeared to be satisfied based on the documentation found during DEA's review of the construction documents. As noted above, the special inspector was Carlson Testing.
    - Section 03300 : Cast-in-Place Concrete –
      Specification required that mix designs limit shrinkage to 0.048 percent at 28 days. Concrete shrinkage can affect the behavior of post-tensioned concrete, therefore, this specification requirement helps to ensure the post-tensioned slabs perform adequately.
- Structural Calculations –
  Structural calculations (issued April 20, 1999) were reviewed and include a section for Post-Tensioned Slab Design. While there are several post-tensioned slab calculations included in this submittal, there is only one post-tensioned slab design for the building. The calculation is labeled ‘2nd Floor – Grid G’. While the input parameters appear to be correct, no deflection calculations were included in the output.

- Requests for Information (RFIs) –
  RFIs are formal questions or requests posed by the contractor during construction to the design team. The following items were noted during DEA's review of the RFIs for the Courthouse Square building:
  - RFI 22 states "Are there more pt cables required between 10 & 10a, K-O?" Structural engineer answered "Yes. See shops for adjustment." DEA was unable to locate pt shop drawings showing a modification.
  - In a letter dated May 5, 1999, Leonard Lodder (with Arbuckle Costic Architects) writes to Glen Cook (with Century West Engineering) saying: "I have recently succeeded in reviewing with the Owner's project manager your request for additional fees to cover perceived changes in scope for the project during the design development and construction document phases of the project. Unfortunately, our review is tempered by the significant number of RFIs from the contractor regarding structural issues. There is considerable concern that the level of completeness of the structural drawings will expose the owners to significant additional costs through change orders." If this is the case and there was a large number of RFIs on the project, the possibility of errors and/or omissions in the construction phase would have increased.
- Shop Drawings –
  Shop drawings are prepared by the post-tensioning/mild reinforcement contractor/supplier and show the layout, placement, sections and details regarding the installation of the reinforcement. Both the post-tensioning and mild reinforcement shop drawings were reviewed by DEA. Both sets of shop drawings appeared to match the permit drawings design intent.
- Special Inspection Reports –
  DEA reviewed several different types of special inspection reports pertaining to the construction of the post-tensioned floor slab. Reviewed reports included concrete cylinder tests, post-tensioning elongation reports and concrete shrinkage tests. These tests are explained/summarized below:
  - Concrete Cylinder Tests –
    Typical concrete special inspection includes taking samples of the field cast concrete and testing for compressive strength at specified intervals (as required in the project specifications). Cylinder test results (Appendix E) for the fifth floor slab (at the surveyed location) were found and reviewed. No errors or omissions were found in these documents.
  - Post-tensioning Elongation Reports –
    Post-tensioning records are required to be made by the special inspector documenting the date of stressing, anchorage force, stressing force, number of tendons, location of tendons, required elongation and elongation attained. Elongation reports were found for the fifth floor slab and appeared to be in conformance with the shop drawings except for the following:
    - There appears to be a discrepancy between the number of tendons indicated on the fifth floor pt shop drawings and the fifth floor elongation reports relative to slab segments at Grids G and H. The

    slab at these locations was checked for the tendon configuration depicted in the elongation reports and appears adequate, but this raises the question as to whether there might have been confusion in the field regarding layout of the banded tendons possibly leading to improper placement.
  - Concrete Shrinkage Tests –
    Specification section 03300 required that concrete mix designs limit shrinkage to 0.048 percent at 28 days. Two concrete shrinkage test reports were found (Appendix E) with shrinkage values identified at 0.43. As there is no information on the reports explaining this value, it is difficult to tell if these shrinkage tests were non-conforming or not. However, it is noted that concrete shrinkage can be a debilitating problem with post-tensioned concrete therefore this raises the question as to if concrete shrinkage is contributing to the excess deflection of the floor slab.
- Concrete Mix Designs –
  Two different mix designs were found (Appendix D) that could have potentially been used in the typical post-tensioned concrete floor slabs at the Courthouse Square building. The first was identified as design # 5K-3FM and the second was identified as design #5K-4FM. It is assumed that mix design #5K-4FM was the mix that was actually used in the floor slab construction as this is the one that matched the special inspection reports most closely. This mix design appears to meet the criteria specified in the project specifications.
- Meeting Notes –
  Several meeting notes were found and reviewed by DEA concerning the day to day construction activities of the Courthouse Square project. Nothing unusual or noteworthy was found in these documents.
- Memos –
  Several memos were found and reviewed by DEA concerning the day to day construction activities of the Courthouse Square project. Nothing unusual or noteworthy was found in these documents.
- Photographs –
  DEA reviewed hundreds of site photographs from the construction of the Courthouse Square building. Information that was confirmed by the review of these photographs included the following:
  - The date of the fifth floor slab pour (east side of the building) was confirmed to have taken place on 11/17/1999. This matches the pour date listed on the concrete cylinder tests noted above.
  - General layout of the tendons appears to match the shop drawings. However, all photos of the fifth floor slab pour (east side of the building) are taken from a considerable distance above the floor slab therefore it is impossible to confirm what the as-built conditions were during the floor construction.
- Contractors Project Schedule –
  A copy of the contractors' project schedule was found (Appendix L) and reviewed by DEA. This schedule outlines construction activities beginning at the parking level and ending with the roof level. The schedule shows the fifth floor slab pour

(east side of the building) occurring on 10/22/1999. This shows that there was a delay in construction of approximately one month. An item of note in the contractors schedule is the date at which the contractor planned on stripping the floor slab forms. The schedule identifies this activity as taking place four-ten days after the pour. This appears to be an adequate time frame for removal of the forms.

- Emails –
  Several emails were found and reviewed by DEA concerning the day to day construction activities of the Courthouse Square project. Nothing unusual or noteworthy was found in these documents.
- Structural Observations –
  Structural observations are required by the building code to be performed by the engineer of record. These observations do not take the place of special inspection. In a structural observation report dated February 24, 2000, Tim Terich (with Century West Engineering) states: "Observed the floor grinding of slabs in the west stairs, where the concrete was poured too high. Grinding has exposed 2-3 tendons running parallel to the door opening. The tendons lie within 1"-2" of the top of the slab. These tendons are not significant to the integrity of the slab." The tendons Mr. Terich refers to are distributed tendons running in the east-west direction. The removal of these tendons would not be expected to impact the slabs structural integrity. However, this does raise the question as to whether other, more important, tendons were cut in the field in a similar fashion without documentation.
- Field Sketches –
  Field sketches are typically issued by the contractor to clarify design intent or to troubleshoot issues that arise in the field. A field sketch was found (Appendix N) by DEA which states that the post-tensioned concrete slab experienced shrinkage which created problems with the connections at the exterior, non-bearing metal stud framing. The sketch does not make clear where this situation occurred at in the building. It also does not make clear the magnitude of this reported shrinkage. Although this is not a clear indicator that excessive shrinkage of the post-tensioned floor slabs was occurring, due to the circumstances noted above, it is an issue that should be considered when examining possible causes for the floor slab deflection.

STRUCTURAL EVALUATION

The following (along with brief descriptions of each) were identified as possible causes of the excessive deflection at the office floor slab:

- Concrete Shrinkage –
  Shrinkage is the shortening of concrete during hardening and drying under constant temperature. Drying shrinkage occurs due to the loss of a layer of adsorbed water from the surface of the gel particles.
- Concrete Creep –

Creep is a time-dependant deformation that begins immediately after construction but continues at a decreasing rate for as long as the concrete is loaded. In floor slab construction this deformation takes the form of slab deflection or settlement. The amount of creep that can occur is dependant on the magnitude of load and the strength of the concrete when the load is applied. Assuming that the slab was properly designed, the compressive strength of the concrete when load was applied would be the primary cause for creep. Most creep occurs within the first year of service and tapers off as the concrete reaches its maximum compressive strength.

- <u>Premature Removal of Formwork –</u>
  Removal of formwork for multistory construction should be a part of a planned procedure considering the temporary support of the whole structure as well as that of each individual member. Early removal of formwork could compromise the strength of a structure and increase its potential for excessive deflection. If formwork/shoring is removed prior to the slab reaching its design strength, the potential amount of settlement due to creep would increase.
- <u>Improper Concrete Curing –</u>
  Curing is the process of maintaining freshly placed concrete at a favorable temperature for a suitable period of time during its early stages so that the desired properties of the material can develop. Improper curing can compromise the strength of a structure and increase its potential for excessive deflection.
- <u>Incorrect Placement of Steel Reinforcement –</u>
  Steel tendons and mild reinforcement are typically specified for a post-tensioned concrete slab. It is imperative that the reinforcement is placed per the structural drawings in order that the slab performs as expected. Problems can occur if the incorrect number of tendons/mild reinforcement is placed in the slab. Problems can also occur if the reinforcement is placed at the wrong depth within the slab.
- <u>Inadequate Structural Floor Slab Design –</u>
  The UBC requires that typical floor construction be designed for minimum live loads and must be checked for flexural/shear stresses. Typical floor construction must also be checked to not exceed maximum deflection requirements. A floor slab could be designed so as to meet the flexural/shear requirements but still not meet the deflection requirements. This would be considered a ‘serviceability’ issue, not a ‘life safety’ issue.
- <u>Stress Loss/Slippage of Steel Tendons –</u>
  Typical post-tensioned construction consists of steel tendons that have a live end and a dead end. The live end is the end at which the tendon is stressed. The dead end is the end at which the tendon is anchored. Stress loss can occur if a tendon anchor ‘slips’ due to cracking of the concrete at the anchor location. As the anchorage zones are typically congested, poor consolidation of the concrete can occur leading to slippage of the anchors. Tendons can also slip if the clamping device at the live end is not secure.
- <u>Broken Post-Tensioned Cables –</u>
  Although not common, tendons can break after construction of the post-tensioned element is complete. Broken post-tensioned cables weaken the structure and can present a life safety hazard. Broken post-tensioned cables are not always

detectable by visual observation. If the tendon does not cause cracking or spalling of the element, it may only be detected by x-rays. Tendons are most likely to break (after stressing) when someone accidentally drills through a tendon or when the tendon is damaged corrosion. Corrosion of tendons in an office building where the slab is protected from the weather is rare. It is extremely rare in a building eight years old.

- Service Loads in Excess of Design Loads –
  All structural elements are designed to withstand a set of prescribed loads. Typically, these loads are broken down into live loads (people, movable equipment, etc.) and dead loads (self weight of the structure, fixed furniture, etc.). The Courthouse Square floor slabs were designed (per the permit drawings) for the following live loads:
    - 50 psf – Living Areas
    - 100 psf – Assembly Areas and Hallways

  The floor slab design dead load is not indicated on the permit drawings. It is possible that the service loads (loads that structure actually experiences in its' as-built condition) are greater than the design loads. In this instance, the structure could experience strength failures (lack of flexural or shear strength) or service failures (excessive deflection).
- Inadequate Slab Reinforcement –
  Post-tensioned concrete design is an iterative process and requires a balance between post-tensioning tendons and mild reinforcement. If the amount of reinforcement is inadequate to support the required floor loads, the slab can deflect beyond allowable limits and/or the effects of creep can be increased.

Through the process of completing the tasks previously outlined, the following possible causes were ruled out as not likely being the cause of excessive deflection:

- Inadequate Structural Floor Slab Design –
  Per DEA's independent structural calculations, it appears the original structural floor slab design was adequate.
- Stress Loss/Slippage of Steel Tendons –
  Based on the non-destructive testing outlined above and multiple walk-throughs of the building, there are no indications that slippage of the steel tendons has occurred.
- Broken Post-Tensioned Cables –
  Based on the non-destructive testing outlined above and multiple walk-throughs of the building, it does not seem that there are any broken post-tensioned cables at the area surveyed at the Courthouse Square building. Also, given that the signs of slab settlement were observed consistently at multiple locations on the third, fourth and fifth floors, it is not likely that broken tendons are the cause.
- Service Loads in Excess of Design Loads –
  Based on multiple walk-throughs of the building, it does not appear that service loads in excess of the design loads are being applied to the floor slabs.

The following possible causes can either not be ruled out by DEA based on the lack of information found or because of information found that suggests errors/omissions:

- Concrete Shrinkage –
  Based on the documents outlined previously in this report, there are multiple pieces of evidence that suggest concrete shrinkage occurred at the Courthouse Square building. It is unclear to what extent this shrinkage occurred.
- Concrete Creep –
  The contractors schedule outlined previously in this report suggest that the formwork/shoring of the fifth floor slab was removed within an acceptable period of time after the slab was poured. However, this appeared to be a preliminary schedule and the lack of additional documentation regarding this scope of work suggests that it is possible this could be a contributing factor to the excess deflection of the slab.
- Premature Removal of Formwork –
  Based on the schedule outlined by Pence Kelly (Appendix L) it appears that the removal of the forms at the fifth floor slab occurred at an acceptable length of time after the concrete was poured. However, this document is an estimate and can not be confirmed as to if this schedule was followed in the field.
- Improper Concrete Curing –
  Based on the specifications, it appears that acceptable curing techniques were in place to optimize the performance of the floor slab. However, not enough documentation was found to rule this out as a possible cause of the excessive deflection.

The following possible causes have been confirmed to be directly contributing to the excessive deflection at the fifth floor slab at the surveyed area noted above.

- Incorrect Placement of Steel Reinforcement –
  Based on the GPR testing (outlined previously in this report), it appears that the banded tendons at Grid L between Grids 10 and 11 were incorrectly placed within the slab. Per DEA's independent structural calculations, we have shown that the change in profile of the tendons from the shop drawings to the as-built conditions adds approximately 1” of additional deflection to the slab. Structural calculations were also completed to check what affect excluding two tendons would have on the deflection of the slab (as noted previously in this report, based on the x-ray testing, there is a possibility two tendons were excluded during the construction of the slab). This change would add approximately ¼” of additional deflection to the slab.

  Although it is unclear whether or not the correct number of tendons were placed in the slab at Grid L between Grids 10 and 11, it is obvious that the tendons that are in the slab at this location were placed at the incorrect profile. DEA could not find any special inspection reports listing the placement of the post-tensioning as a non-conforming item. It is possible that the tendons were not inspected or that they were inspected and then moved at a later date.

RECOMMENDATIONS

Based on this evaluation, the likely causes of the excessive slab deflection at the Courthouse Square building have been narrowed to the following:

- Incorrect Placement of Steel Reinforcement
- Concrete Shrinkage
- Concrete Creep
- Premature Removal of Formwork
- Improper Concrete Curing

Based on the fact that survey results show that the existing slab is not continuing to deflect, there are two methods of repair Marion County can choose to implement.

One option is to leave the slab as it is, assuming it will not deflect anymore. Marion County could redo the damaged partition framing (at the fifth floor) under the theory that the damage will not return.

The second option would be to strengthen the existing floor slab with the hopes of ensuring no future deflection will occur. One of the following repair methods could be implemented if this is the route the County chooses:

- <u>Fiber Reinforced Polymer (FRP)</u> –
  FRP materials are composites consisting of high-strength fibers encapsulated in a polymeric resin to form a laminate. Fibers in FRP composite materials carry the load, while the resin protects the fibers and keeps them in the alignment. In addition to encapsulating the fibers, the resin acts as an adhesive to bond the laminate to the concrete substrate. The fibers are typically provided in a woven sheet matrix, procured laminates, or solid bars.

- <u>External Post-Tensioning</u> –
  External post-tensioning consists of prestressing tendons externally attached to the structural element at anchor points, typically located at member ends. Uplift forces are introduced to the member at specific locations along its span. By controlling the tendons profile along the member, the desired level of capacity and serviceability improvement is achieved.

- <u>Retension Existing Steel Tendons</u> –
  Retensioning the existing steel tendons would consist of shoring the existing construction, exposing the live ends of the banded tendons and restressing the cables.